Osseoperception: Active Tactile Sensibility of Osseointegrated Dental Implants

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Purpose: The phenomenon of developing a certain tactile sensibility through osseointegrated dental implants is called osseoperception. Active tactile sensibility can be tested by having the subject bite on test bodies. The aim of the study was to describe the active tactile sensitivity of single-tooth implants based on the 50% value and the slope of the sensitivity curve at the 50% value. Materials and Methods: Sixty-two subjects with single-tooth implants with natural opposing teeth were included in the study. In a computer-assisted and randomized way, copper foils of varying thickness (0 to 200 µm) were placed interocclusally between the single-tooth implant and the natural opposing tooth, and the active tactile perception was studied according to the psychophysical method of constant stimuli and statistically evaluated by logistic regression. Results: Tactile perception of the implants at the 50% value estimated by logistic regression was 20.2 ± 10.9 µm on average, and the slope was 29 ± 15. Regarding implant surface structure, significant differences were observed. The sandblasted and acid-etched surface was significantly more sensitive than the titanium plasma-sprayed surface, and the machined surface was similar to the titanium plasma-sprayed surface. Conclusions: Active tactile sensibility of implants with natural antagonistic teeth is very similar to that of teeth, but the slope of the tactile sensitivity curve is flatter. Significant differences in tactile sensibility as a function of different implant surfaces may indicate that receptors near the implant form the basis of osseoperception. INT J ORAL MAXILLOFAC IMPLANTS 2010;25:1159–1167

Key words: active tactile sensibility, dental implants, interdental perception sensibility, occlusion, osseoperception, surface properties
stimuli. Moreover, a great density of neuropeptides was detected in the bone marrow. In animal experiments, it was shown that implant materials are surrounded by nerve fibers in the area of the bone-implant interface and that there is a negative correlation between bone contact rate and nerve density. This led to the hypothesis that the nerves originate from residues of the periodontal tissue of extracted teeth and that therefore the tactile perception of the implant would be lower the longer the natural tooth has been absent and that different implant surfaces, because of differing bone apposition rates, might cause different degrees of tactile perception.

More remote proprioceptors and exteroceptors that are excited by the mechanical load on the peri-implant bone have also been discussed as the basis for osseoperception. Passive tactile sensibility seems to be less clearly localized in the case of implants versus natural teeth and is perceived by the test persons as being transmitted more deeply in the skull, i.e., the deformation of the peri-implant bone, which might cause stretching of the periosteum. The periosteum contains many free nerve endings that are important pain transmitters and Golgi-Mazzoni bodies that respond to pressure sensations. In addition to the deformation of the hard bone substance, an interstitial fluid shift in the narrow canaliculi and lacunae of the cancellous bone may also transmit mechanical stimuli to more remote receptors. Thus, regarding tactile perception, tendon and muscle spindles, as well as receptors in the temporomandibular joint corresponding to the Paccini type, also have to be considered. In passive tactile sensibility tests, maxillary implants demonstrated a more elevated stimulation threshold than mandibular implants; this may indicate an involvement of the muscle, tendon, and joint receptors in the transmission of stimuli in mandibular implants.

However, the physiologic basis of tactile perception through osseointegrated implants, summarized by the term osseoperception, is not yet fully understood. The study of passive tactile sensibility only allows the testing of individual neural receptors, whereas active tactile sensibility more effectively represents normal function and is therefore more relevant for practical dentistry. There are many studies dealing with passive tactile perception (i.e., pressure sensitivity) of dental implants, but few studies to date have examined active tactile perception; these few investigations produced contradictory results and were usually made with a small number of test persons (Table 1). In psychophysical sensitivity tests, some patient-specific factors, such as age and gender, affected the test result. For this reason, in addition to anatomical and implant-specific parameters, the subjects’ age and gender have to be considered as potential influencing factors when studying tactile sensibility.

### MATERIALS AND METHODS

#### Experimental Design

The active tactile perception of single-tooth implants was to be investigated by the psychophysical method of constant stimuli in a randomized, single-blinded study and statistically evaluated by means of logistic regression as a psychometric function. In addition to the absolute value in microns at the 50% value, the individual slope was also to be calculated as a characteristic of the individual tactile sensibility curve. Moreover, signs that may point to the physiologic basis of osseoperception were to be recorded. Therefore, the age and gender of the test subjects as well as the effects of anatomical and implant-specific parameters (Table 2) on individual tactile sensibility values were to be analyzed and described.

#### Subject Population

The sample included 62 subjects with single-tooth implants with natural, healthy antagonists: 29 men with a mean age of 47.7 ± 17.6 years and 33 women with a mean age of 43.8 ± 15.4 years. Twenty-two

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**Table 1 Findings in the Literature Regarding Active Tactile Sensibility of Implants Occluding Against Natural Antagonists**

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
<th>n</th>
<th>Foil material</th>
<th>Mean active tactile sensibility (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tzakis et al</td>
<td>1990</td>
<td>14</td>
<td>Aluminum</td>
<td>70</td>
</tr>
<tr>
<td>Mericske-Stern et al</td>
<td>1995</td>
<td>21</td>
<td>Steel</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Lundqvist and Haraldson</td>
<td>1990</td>
<td>21</td>
<td>Plastic</td>
<td>18</td>
</tr>
<tr>
<td>Lundqvist and Haraldson</td>
<td>1992</td>
<td>17</td>
<td>Plastic</td>
<td>20</td>
</tr>
<tr>
<td>Fenton and Lundqvist</td>
<td>1981</td>
<td>–</td>
<td>Plastic</td>
<td>15</td>
</tr>
<tr>
<td>Jacobs and van Steenberghe</td>
<td>1991</td>
<td>13</td>
<td>Steel</td>
<td>48</td>
</tr>
<tr>
<td>Batista et al</td>
<td>2008</td>
<td>10</td>
<td>Aluminum</td>
<td>10</td>
</tr>
</tbody>
</table>
implants were located in the anterior arch and 40 were in posterior regions; 37 implants were in the maxilla and 25 were in the mandible. The implants had been restored with metal-ceramic restorations, ie, fully ceramic veneered single crowns with a cast metal framework. The implant surface structures were: 32 titanium plasma-sprayed (TPS), 14 sand-blasted/acid-etched (SAE), and 16 machined. The mean length of the implants was $11.7 \pm 2.8$ mm (range, 8 to 18 mm). The diameter of the implants ranged between 3.3 and 6.5 mm, with a mean of $3.9 \pm 0.6$ mm. The patients were informed in detail about the study procedure and signed an informed consent document. The study was performed in compliance with good clinical practice and the Declaration of Helsinki (last revised in Edinburgh 2000); the study protocol was reviewed and approved by the ethics committee of the Faculty of Medicine, University of Bonn, Germany.

**Clinical Procedure and Randomization**

Interocclusal copper foils, 5 to 200 µm, were positioned on the teeth of the test subjects, who were asked to bite briefly on them and indicate whether or not they felt the foreign bodies. Because foreign bodies between the teeth can be felt not only when biting on them but also heard via bone conduction, headphones were placed on the ears of the test persons, which transmitted "white" and "pink" noise from a cassette tape recorder at the highest possible sound volume. Via a mixing console and a microphone, the examiner could give instructions to the participants through the headphones. The foil thicknesses at which, according to the relevant literature, the threshold value of the tactile sensibility was assumed to be reached, were tested by a greater number of repetitions. The details of the study setup concerning the different foil thicknesses and the number of repetitions can be found elsewhere. The sequence of the 14 different foil thicknesses ($n = 140$) and interspersed mock trials ($n = 20$) was randomized among all 160 test runs per test person. The randomization of the foil thickness was provided by computer software designed for this purpose (MedStats, University of Bonn). Thus, before every test run, the software assigned the foil thickness to be used. The participants were blinded and there was no ascending or descending sequence of the foil thicknesses. By pressing the keys of a computer mouse, the test person indicated after every round whether or not he had felt something between his teeth. This output was stored directly in the computer and categorized by foil thickness (MedStats). Figure 1 illustrates the study setup.
Statistics
All test results recorded were included in the evaluation. Tactile sensibility was calculated by means of logistic regression as an estimated 50% value of correct answers. With this evaluation method, not only a 50% value but also the respective slope of the tactile sensibility curve can be obtained. Anatomical and implant-specific parameters as well as the subjects’ age and gender were analyzed descriptively for their influence on active tactile sensibility with the nonparametric Kruskal-Wallis test. In case of a significant outcome, the nonparametric Wilcoxon test with Bonferroni-Holm correction was used to allocate the differences. All statistical comparisons were carried out as two-sided tests with alpha ≤ .05. Sample size calculations were done using the Kieser and Hauschke formula.46

RESULTS
The results showed a mean tactile sensibility of 20.2 ± 10.9 µm for the combination of single-tooth implant and natural healthy antagonist. All recorded test results are shown in Fig 2. The mean slope at the 50% value was 29 ± 15. Overall, there was a negative correlation between the 50% value and the slope; the bigger the 50% value, the smaller the slope value. However, there were also large interindividual differences between the test subjects regarding the 50% values and the slopes (Table 3).

The age or gender of the test subjects did not affect the results. Only the implant-specific parameter of surface structure demonstrated a significant influence (P = .0230); the implants with an SAE surface appeared to have a better active tactile sensibility opposing a natural antagonistic tooth than TPS implants or implants with a machined surface. The 50% values for the machined surface were similar to those for the TPS surface. In individual comparisons, the difference between the TPS and SAE surfaces was statistically significant (P = .016). The mean difference was 8 µm, and the median was 10 µm (Table 4). None of the other anatomical and implant-specific parameters investigated had any effect on tactile perception.

DISCUSSION
Because foreign bodies between the teeth cannot only be felt but also heard by bone conduction when the teeth occlude, participants in the present study were exposed to special noise through headphones.47,48 It may be assumed that this measure limited their perception to the sense of touch.49 In the final interviews, the subjects confirmed that they did not hear the biting on the foils. However, the chewing pressure and dynamics of tactile motions could not be standardized.

The test strips were manufactured from high-precision copper foils that adapt to the occlusal relief as a result of their high ductility. This ensured that the intended interocclusal clearance could be achieved during testing with the highest possible precision. However, the possibility that thermal sensations were transmitted to the teeth being tested cannot be ruled out because of the thermal conductivity of the copper material used. This could then distort the absolute values measured.50 Because the study was

Fig 2 Test results from all implants (n = 62).
conducted at an ambient temperature of approximately 25°C, the resulting thermal reaction could only be very minor. To what extent sensibility is dependent on the natural antagonist could not be estimated, but this situation is similar to other previously published studies concerning this topic.

Because a relatively long time of about 2 hours was needed for the test, a learning effect and declining concentration of the subjects attributed to fatigue were observed. A study setup with decreasing foil thickness, often used in the past, leads to a learning curve and thus to better results for thinner foils.\textsuperscript{51} In the present study, these effects on the 50% values were compensated by randomizing the foil thickness. The study design conforms to the requirements for psychometric trials with the method of constant stimuli.\textsuperscript{43,52}

The mean value of 20.2 ± 10.9 µm for active tactile perception confirms the low values that have been found to date for implants versus natural teeth in the published literature.\textsuperscript{2,38–41,44,45} on the subject and is comparable to that seen with natural teeth of older test persons.\textsuperscript{44,53} Age and gender did not have any effect on tactile perception, but it is known that in older individuals the tactile perception of natural teeth does depend on age.\textsuperscript{53} In a logistic regression model, the tactile perception curves for implants showed a flatter slope than those for natural teeth: 29 ± 15 (slope for implants) versus 45 ± 61 (slope for teeth).\textsuperscript{44}

In the case of a flat slope, the 50% value represents a point along a slowly progressing gradient, whereas for the steeper slope the 50% value instead appears to be a threshold or limit of the patient’s tactile sensibility. The two examples (Figs 3 and 4) provided show patients with high 50% values; patient A showed a flat slope and patient B had a somewhat steeper slope. When the 50% values were very low, the slopes necessarily were very steep because the range of values did not start before zero. Flatter slopes at higher 50% values, however, meant that the test person’s uncertainty with regard to his tactile capabilities correlated with the level of the 50% values. Therefore the lower values of slopes of implants compared to those of teeth could indicate that the uncertainty of feeling foreign bodies is more pronounced for implants than it is for natural teeth.\textsuperscript{44}

Because the material used to build the prosthetic rehabilitation is of importance regarding active tactile sensibility, only metal-ceramic single crowns were included in the present study. To achieve low threshold values for the active tactile sensibility of implant crowns as in the present study, it seems to be necessary to rebuild a missing tooth that is as similar to the original tooth as possible. This includes the design of the occlusal surface and the type of veneering material, for which ceramic seems to be more favorable than acrylic resin.\textsuperscript{54}

Implant surface, implant geometry (ie, length and diameter), and, related to it, the extent of bone apposition to the implant, might be of importance in the study of osseoperception. In Periotest trials, implants with a small diameter and, accordingly, a small surface, demonstrated a markedly weaker bone-to-implant attachment.\textsuperscript{26} In the present study, implant geometry, ie, length and diameter of the implants, did not affect tactile perception. The surface structure, however, resulted in statistically significant differences ($P = .0230$); implants with an SAE surface were more sensitive than machined implants and implants

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Active Tactile Sensibility of Dental Implants Described with the 50% Value and the Slope of the Sensibility Curve (Logistic Regression)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n</td>
<td>Mean</td>
</tr>
<tr>
<td>50% value (µm)</td>
<td>62</td>
</tr>
<tr>
<td>Slope at the 50% value</td>
<td>62</td>
</tr>
</tbody>
</table>

SD = standard deviation; CI = confidence interval.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Comparison of 50% Value Versus Implant Surface (n = 62)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface</td>
<td>n</td>
</tr>
<tr>
<td>TPS</td>
<td>32</td>
</tr>
<tr>
<td>SAE</td>
<td>14</td>
</tr>
<tr>
<td>Machined</td>
<td>16</td>
</tr>
</tbody>
</table>

SD = standard deviation; CI = confidence interval.
with a TPS surface. In dog models the dependence of tactile perception on implant surface structure has also been shown.\textsuperscript{21} Forces applied to osseointegrated implants produced afferent nerve signals to the brain, and depending on the surface structure (aluminum oxide, titanium oxide, or hydroxylapatite coated), differences were detected in the histologic follow-up examination; there was a negative correlation between bone contact and nerve density.

An increase in the roughness of the implant surface is supposed to enhance the bone-to-implant contact rate.\textsuperscript{55} However, a moderately rough surface (1 to 2 \( \mu m \) \( S_A \) value; eg, SAE) is more likely to have a higher bone-to-implant contact rate than a very rough surface (> 2 \( \mu m \) \( S_A \) value; eg, TPS) or a minimally rough surface (0.5 to 1 \( \mu m \) \( S_A \) value; eg, machined).\textsuperscript{56} Thus, in the present study, the bone-to-implant contact rate of the SAE implants might have been higher than those of the machined or the TPS implants, and the decreased threshold level of the active tactile sensitivity of the SAE implants was therefore a result of the increased bone-to-implant contact percentage. Even though an osseointegrated implant is ankylosed by the surrounding bone, it still has a certain physiologic amount of mobility, which is in size a tenth of the physiologic mobility of a natural tooth. This mobility is caused by the elastic deformation of the peri-implant bone when lateral or axial forces are applied on the implant superstructure.\textsuperscript{57,58} If there is a lower bone-to-implant contact percentage, the resistance of the surrounding bone to deformation might also be reduced. This slightly accelerated mobility of the

\textbf{Fig 3} Results from test person A.

\textbf{Fig 4} Results from test person B.
implant and the accelerated deformation of the bone might result in mechanical stimuli for local receptors or more remote receptors transmitted via an interstitial fluid shift in the narrow canaliculi and lacunae of the cancellous bone.31

Concerning changes in tactile sensibility during the time of prosthetic loading, conflicting findings are available in the relevant literature. Some studies have described an increase in the tactile perception capability of osseointegrated implants over time,51,59,60 whereas others did not find any such change over time, which is in agreement with the present study.12,61

Implants in the maxilla and mandible and in the anterior and posterior region were found to have similar tactile perception values. Statements that mandibular implants may be more sensitive than maxillary implants35 could not be confirmed by the present study.

The hypothesis that osseoperception is caused by remaining parts of the periodontium of the extracted teeth21 and that, consequently, early implantation after tooth extraction will lead to better tactile perception than later implantation could not be confirmed by the present study either. A tactile perception trial with implants placed in iliac crest bone grafts, which do not have any periodontal structures, produced results that were similar to those with implants placed in local bone and supports the results of the present study.62 However, via their periodontal receptors, the antagonistic natural teeth of the tested implants probably had an influence on the measurements. Because these teeth were all healthy, their influence on the results could be estimated as similar for all test subjects.42,50,52,67 Thus, the measured differences in the 50% threshold levels in the present study may be a result of the different surface structures of the implants. Batista et al2 found no statistically significant difference between the active tactile threshold levels of persons with only natural teeth (10 µm), persons with implant-retained fixed prostheses occluding against natural teeth (10 µm), and persons with occluding implant-retained fixed prostheses in both arches (14 µm). In all groups, the threshold levels were very low.2 Additionally, in a recent study it was shown that anesthetizing the natural antagonist of a single-tooth implant altered the active tactile sensibility threshold only minimally. The mean thresholds of 20 ± 11 µm for single-tooth implants with an anesthetized natural antagonist64 and without anesthesia (20.2 ± 10.9 µm seen in the present study) are similar. Apparently, the active tactile sensibility of single-tooth implants with natural opposing teeth cannot be attributed only to the periodontium of the opposing tooth. In the present study, in addition the periodontal structures of the natural opposing teeth, the presence of natural teeth adjacent to single-tooth implants could also explain the equivalent tactile capability of single-tooth implants and natural teeth.65,66 In addition to the periodontal receptors, muscle or tendon spindles or adjacent periosteal receptors could contribute to the interocclusal tactile perception of single-tooth implants. The application of forces to the mandible and transmission of them via a deformation of the corpus of the mandible or an interstitial fluid shift in the mandibular cancellous bone could activate these receptors. Neuroanatomical findings obtained with functional magnetic resonance imaging showed an activation of the primary sensorimotor cortex in persons with implant-supported dentures that was different from that of patients with complete dentures.67 This could support the hypothesis that the implant may have a tactile sensibility of its own.

Because there are no published data available regarding the active tactile sensibility of occluding single-tooth implants, further studies are needed. Also, the impact of the implant itself on the active tactile sensibility should be further investigated through measurement of the action potentials of the implant or with functional magnetic resonance imaging.

**CONCLUSIONS**

The mean value of 20.2 ± 10.9 µm observed in the present study for active tactile perception confirmed the low values that have been observed to date for single-tooth implants versus natural teeth in the published literature2,28,41,44,45 and was comparable to the perception of natural teeth of older test persons.44 The findings that the tactile sensibility of implants, in contrast to that of natural teeth,44,53 was not affected by age, that the tactile sensibility curves of implants were flatter than those of natural teeth,44 and that tactile perception was found to depend on the implant surface structure indicate that tactile perception may not only result from the periodontal structures of the remaining dentition. The significant differences in the tactile perception of different implant surface structures might point to receptors near the implants as the anatomical basis of osseoperception.

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REFERENCES


